

**DESIGN OF FEEDER ROUTE NETWORK USING COMBINED GENETIC ALGORITHM AND
SPECIALIZED REPAIR HEURISTIC**

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ABSTRACT

In metropolitan cities an efficient integrated public transportation system is unavoidable in order to restrict unsustainable growth of private and intermediate transport modes. Well designed feeder routes and coordinated schedules to minimize transfer time from main transit to feeder buses play an important role. Past literature reveals that heuristic approach had been popular for design of routes and had been applied successfully in verities of network design problems. Non traditional optimisation technique especially Genetic Algorithms are also found to be very effective in generation of optimised feeder routes and schedules. In this research Genetic Algorithm first develops feeder routes and then a specialized heuristic Algorithm works as repair algorithm in order to satisfy demand of all the nodes. Thus the advantages of both Genetic Algorithm and Specialized Heuristic Algorithm are obtained in this method. The developed feeder route structure is found to be better in terms of load factors in buses, satisfaction of demand and waiting time for feeder buses as compared to existing scenario and earlier approaches adopted by authors far the same study area.

INTRODUCTION

In metropolitan cities of developed and developing countries suburban railway and public buses are the most common public transport carriers. Commuters' dissatisfaction towards public transport system increases due to increased travel time, poor level of comfort, uneconomical operations and due to higher out of vehicle time especially at transfer points. These problems can be solved by appropriate coordination among major public transport modes. The successful coordination implies

- Traveller's ability to transfer freely and conveniently between modes.
- Distinct service areas between each modes thereby minimising duplication of services.
- Adjustment and interrelationship of schedules and
- Joint fare structure

A poorly coordinated transfer can require long, irregular wait for infrequent connecting services. The point of balance between travellers demand for direct service and transit operator's need for economy often lies with the level of attention given to the details of the transfer movement. Thus well designed feeder routes satisfying maximum demand with acceptable travel time are of prime concern. In order to minimise transfer time coordinated schedules have to be optimised.

Literature Review and Objective of Study

Many research studies are conducted for bus route network design problems involving development of routes and schedules. Lampkin and Saalmans (1967), Silman et al (1974), Dubois et al (1979), Mandl (1980), Baaj and Mahmassani (1995) developed bus routes using heuristic approach. Shrivastava and Dhingra (2001) successfully implemented heuristic approach for design of feeder routes for feeder public buses at suburban railway stations. Thus heuristic algorithms are not theoretically rigorous but have been used successfully for real size network and capable of giving sub optimal values. Genetic Algorithms (GAs) which are robust optimization technique have been used successfully for routing and scheduling problems. Pattnaik et al (1998), Gundaliya et al (2000) and Tom and Mohan (2003) used Genetic Algorithms for the design of bus route network. Shrivastava and Dhingra (2002) developed successfully coordinated schedules of public buses for existing schedules of suburban trains on the developed feeder route network using Genetic Algorithms. Chien et al (2003) presented a model for optimizing service headway and a bus route serving an area with a commuter (many-to-one) travel pattern. The bus

route is optimized by minimizing the total system cost, including operator and user costs, while considering diagonal links in the study network. Zhao and Ubaka (2004) presented a mathematical methodology for transit route network optimization. The goal was to develop effective computational tool for the optimization of large – scale transit route networks. The objectives were to minimize transfers and optimize route directness while maximizing service coverage. Agrawal and Mathew (2004) proposed two parallel genetic algorithm (PGA) models. The first was a global parallel virtual machine (PVM) parallel GA model. The second was a global message passing interface (MPI) parallel GA model. It was observed that the global PVM model performs better than the other. Fan and Machemehl (2004) formulated a multi – objective nonlinear mixed integer model for transit route network design problem (TRNDP). The proposed solution framework was consisting three main components: an Initial Candidate Route Set Generation Procedure (ICRSGP); a network analysis procedure; and a Heuristic Search Procedure (HSP). Five heuristic algorithms, including the Genetic Algorithm, local search, simulated annealing, random search and tabu search are employed as solution methods for finding an optimal set of routes from the huge solution space. Sensitivity analysis for each algorithm was conducted and model comparisons were performed.

Authors have communicated research papers on the development of feeder routes for the same study area using different approaches. In one of the research papers (Shrivastava and O’Mahony, Jan 2005) the authors developed feeder routes using a heuristic algorithm which was found to be very effective and demand of all the nodes was satisfied by the developed set of routes. Due to heuristic approach set of the routes can not be guaranteed to be at optimal level, it may give sub optimal results also. In another research (Shrivastava and O’Mahony, 2006) the authors developed feeder routes and schedules simultaneously using Genetic Algorithms for the same study area. The developed routes and schedules were optimum but the entire demand was not satisfied. This is because in the typical study area some of the nodes were not having good connectivity with other nodes. In view of this instead of 17 nodes only 16 were selected, the remotest node in the study area was not included. In this paper both of the approaches are combined and thus the benefits of both of them are obtained. The optimal set of feeder routes are first developed by Genetic Algorithms and if any demand remains unsatisfied, it is inserted / attached to best possible route by specialized heuristic approach which works as a repair algorithm. Thus the advantages of both the approaches are achieved in this research.

The objective of the proposed research is development of feeder bus route network and coordinated schedules for public buses for the existing schedules of main transit (suburban train) at the given DART station. To

satisfy the entire demand the routes developed by Genetic Algorithms were modified by a well designed heuristic approach. Finally the modified routes are used for determination of coordinated schedules. As a case study, Dun Laoghaire DART station was selected. Dun Laoghaire is a rapidly growing suburb of Dublin city in Ireland. The coordination between DART services and Dublin buses (public buses) for this DART station is attempted.

DATA COLLECTION

The Dublin Area Rapid Transit (DART) is a suburban railway system in Dublin, running basically along the coastline of Dublin Bay from Greystones to Howth and Malahide. There are 32 stations on the existing DART line. Lack of coordination between public buses and DART services has been observed even during peak hours at many stations. Dun Laoghaire is one of the prominent DART stations from where large number of trips originate. It was decided to select Dun Laoghaire as the study area due to its land use pattern which allows greater scope of feeder bus services from the station. Considerable movement of commuters takes place towards many areas from the DART station.

Typical traffic surveys were conducted during the morning peak period i.e. 7 to 9 a.m. on April 28, 2004. It was observed that the maximum number of commuters travel during 8 to 9 a.m. Therefore this time period is identified as peak hour. It has been confirmed during traffic surveys that after 9 a.m. commuter traffic starts decreasing and becomes very less after 9.30 a.m. onwards. During the traffic surveys, commuters exiting the DART station were counted manually. Traffic surveyors conducted sample interviews of commuters leaving the DART station. Enquiries were made regarding their destinations, mode of transport and travel time to their destinations from DART station. Commuters not opting public buses for their further journeys were also enquired about their willingness to shift to public buses if buses are coordinated with DART services in future. It was found that 40% of commuters have their working places very near to DART station and they have to walk about 5 minutes. These commuters were not interested in shifting to public buses even if they are well coordinated with DART services. The percentage of commuters willing to shift to public buses were added to those who use public buses and a potential demand matrix for public buses was developed. It was found that there are 16 destinations (nodes) for which demand exist from DART station. Table 1 indicates potential demands to various destinations. It was also observed during traffic surveys that in the morning peak period the trains towards city centre (north bound trains) contribute about 30% passengers; the remaining 70% were by trains from city centre (south bound trains). There were nine

north bound and eight south bound trains during the peak hour of 8 to 9 a.m. The schedule coordination for feeder buses is attempted for these trains during the indicated peak hour.

PROPOSED METHODOLOGY

The overall methodology for development of feeder routes and coordinated schedules is presented in figure 1. The methodology is explained in following steps.

Step 1:

Potential demand matrix is developed with origin as DART station and destinations as identified in traffic surveys.

Step 2:

Travel distance matrix and connectivity details among various nodes were obtained from the map (Dublin street map, 2000). Travel distance matrix was converted into travel time matrix in 'minutes' using an average speed of 15 Km / hr to address the existing congestion level and road geometrics of influence area (Scot Wilson, 2000).

Step 3:

Other parameters are decided like capacity of buses, minimum and maximum load factors, maximum fleet size, minimum frequency per hour, multiplying constants to convert user and operator costs into monetary value of 'euro', minimum and maximum lengths of routes.

Step 4:

Using the K-Path Algorithm (Eppstein David, 1994) K- shortest paths were developed between DART station and a set of destinations which is well scattered and covers entire influence area. The value of 'K' is adopted as five for the case study.

In this research work destinations were decided based on their locations so that larger portion of feeder route network is optimized by Genetic Algorithm and repair heuristic is used only for few nodes. In view of this various set of destinations which were located away from origin and well scattered in the influence area were selected. The set of destinations were selected for which maximum demand is satisfied with least number of 'k' paths using Genetic Algorithm and few node/nodes are left for repair heuristic.

With the help of traffic surveys various locations (nodes) to which demand exist were identified. The selected set of nodes based on above criteria for which k – paths were developed are identified as potential destinations.

K – indicates number of short paths which can be developed between a given origin (DART station) and potential destination. These short paths are developed in the increasing order of their lengths. In this research, value of ‘k’ is selected as five i.e. between each origin (DART Station) and potential destination. Five short paths are developed, of which first one is smallest and the last one is the largest. Out of these k – paths best one is selected after application of Genetic Algorithm (corresponding to optimized penalized objective function)

Step 5:

The programme to calculate penalised objective function (summation of objective function and penalties due to violation of constraints) is developed in ‘C++’ environment. The set of k – paths (five in number for our case study for each origin and potential destination) are used with Genetic Algorithm. The coding of a path and its corresponding frequency are done together in one string only. The binary digit coding to represent routes and schedules together has been adopted. The set of ‘k– paths’ and frequencies for which objective function along with penalties is minimum is selected as optimized routes and frequencies. These routes are used for application of specialized heuristics discussed in further steps. The frequencies are used to derive coordinated schedules for the existing schedules of DARTs. The details of objective function, penalties and application of GAs are discussed below.

Details of Objective Function, Penalties and use of GAs

The objective function is adopted as minimization of user’s and operator’s costs. The user’s cost is summation of in-vehicle time cost, transfer time cost between DARTs and buses. Operator’s cost is associated to running cost (vehicle operation cost) of buses. Constraints are related to load factor, fleet size and unsatisfied demand. Mathematically, the objective function and various constraints are as follows:

Objective Function

Minimize Total cost, $Z = \{\text{Transfer time cost between DARTs and Coordinating buses} + \text{travel time cost in buses on selected routes (In Vehicle time cost in buses)} + \text{Vehicle operation cost (VOC of Dublin buses)}\}$

Mathematically it can be expressed as

Minimize

$$\leftarrow \text{Transfer Time between } n^{\text{th}} \text{ and } s^{\text{th}} \text{ bound DARTs and buses (1}^{\text{st}} \text{ term)} \rightarrow$$

$$C_1 \left\{ \sum_j \sum_u \sum_l \text{pass}_j^u (\text{bus}_j^l - \text{dart}^u) \delta_j^{u,l} + \sum_j \sum_u \sum_l \text{pass}_j^v (\text{bus}_j^l - \text{dart}^v) \delta_j^{v,l} \right\} +$$

$$C_2 \left\{ \sum_j \text{pass}_j \times t_{\text{inv}_j} \right\} + C_3 \left\{ \sum_j f_j T l_j \right\} \quad \text{----- (1)}$$

$\leftarrow$ In vehicle time $\rightarrow$ $\leftarrow$ VOC $\rightarrow$
 in bus (2nd term) (3rd term)

Constraints

$$1. \quad \frac{Q_{j, \max}}{N_j \times CAP} \leq L_{\max} \quad \text{Maximum load factor constraint (2)}$$

$$2. \quad \frac{Q_{j, \max}}{N_j \times CAP} \geq L_{\min} \quad \text{Minimum load factor constraint (3)}$$

$$3. \quad \sum_{j \in SR} NB_j = \sum_{k \in SR} \frac{N_j * (RT) j}{TP} \leq W \text{ (for all } j \leq SR) \quad \text{Fleet size constraint (4)}$$

$$4. \quad \sum_j d_{\text{unsat}} = 0 \quad \text{Unsatisfied demand constraint (5)}$$

Where,

j = Number of routes available at each stations (as per number of potential selected destinations)

l = Number of buses available for u^{th} north bound DART and v^{th} south bound DART

VOC = Vehicle operating cost for Dublin buses

C_1 = Cost of transfer time in Euro per minute, 11.32 cents/minute for the case study, (Steer Davies, 1994).

C_2 = Cost of in vehicle time in Dublin buses, 0.076 cents/minute for the case study (Steer Davies, 1994).

C_3 = Cost of operation of Dublin bus per Km., € 3.66 for Dublin buses for the case study, (Scot Wilson, 2000).

pass_j^u = Passengers transferring from u^{th} north bound DART to j^{th} route.

pass_j^v = Passengers transferring from v^{th} south bound DART to j^{th} route.

pass_j = Total number of passengers transferring to j^{th} route

bus_j^l = Departure of l^{th} bus on j^{th} route

dart^u = Arrival of u^{th} north bound DART

dart^v = Arrival of v^{th} south bound DART

$\delta_j^{u,l}$ = is a term which shows whether transfer of passengers is possible or not. It attains a value one if transfer from u^{th} north bound DART to l^{th} bus on j^{th} route at DART station is feasible otherwise it attains a value zero.

$\delta_j^{v,l}$ = is also a term which shows whether transfer of passengers is possible or not. It attains a value one if transfer from v^{th} south bound DART to l^{th} bus on j^{th} route at DART station is feasible otherwise it attains a value zero.

$t_{\text{inv},j}$ = In vehicle time in bus on j^{th} route

f_j = Frequency of buses on j^{th} route in terms of number of bus trips per hour.

l_j = length of j^{th} route in kilometers

T = Time period, hours

$Q_{j,\text{max}}$ = Maximum number of passengers on j^{th} route for the given time period.

CAP = Seating capacity of bus, for Dublin buses it is taken as 74 (Scot Wilson, 2000).

L_{max} = Maximum load factor, it is adopted as 1.2 for the case study (Scot Wilson, 2000).

L_{min} = Minimum load factor, adopted as 1 for the case study

d_{unsat} = Unsatisfied demand

SR = Set of Routes

NB_j = Number of buses required in any route 'j'

$(RT)_j$ = Round trip time of the bus on j^{th} route in minutes = $2 t_j$ (in minutes) + layover time (5 minutes for the case study)

t_j = Total travel time on route in minutes including stopping times (Journey time)

TP = Time Period in minutes

N_j = Number of trips per hour times time period in hours under consideration ($f_j * T$)

W = Maximum number of available buses

The first two terms of objective function indicate user's cost and the third term operator's cost. User's cost is taken as summation of costs associated in transferring from DART services (both n^{th} and s^{th} bound) to coordinating buses (first term) and cost of traveling time in buses (second term). The operator cost is in terms of vehicle operating cost, which is proportional to the distance traveled by buses (third term). Constants C_1 , C_2 and C_3 are used to convert each term of objective function in monetary unit of Euro (€). The first and second constraints ensure that the load factor lies within a maximum and a minimum value. If the load factor is less than a maximum value then crowding level will be less and a better level of service will prevail. Level of service should not be less than a minimum value so as to ascertain availability of certain minimum number of passengers for economical

operations. The maximum load factor is the ratio of crush capacity and normal capacity of Dublin buses. The crush capacity is taken as 88 and normal capacity is 74 thus the maximum load factor which is the ratio of the two capacities is taken as 1.2 (Scot Wilson, 2000). The value of minimum load factor is taken as 1.00. Third constraint is associated with the fleet size. This constraint puts the upper limit on maximum number of available buses for operation. Fourth constraint ensures that maximum demand is satisfied and maximum number of commuter get coordinating buses during the period of analysis. The aim of schedule co-ordination is to provide coordinating buses to all commuters who transfer from trains to buses. Thus if more number of commuters are not able to get coordinating buses the penalty should be higher and it is added to objective function so that subsequently GA search for optimal or near optimal values is directed. The penalty corresponding to fourth constraint is proportional to ratio of demand unsatisfied to the capacity of buses. This penalty would have played more realistic role if data collection is done for whole day i.e. till last DART and last available bus.

The objective function and constraints in the study pose a constraint optimization problem; therefore penalty method is adopted for optimization (Deb 1995). Using the Genetic Algorithms the minimum value of penalized objective function is determined (best fitness). The routes and frequencies corresponding to this minimum value are optimal feeder routes and frequencies. These optimal frequencies are used to determine coordinated schedules of feeder buses.

Fitness function = Minimize (Objective Function + Penalties 1 to 4)

Penalty 1: if load factor is more than a maximum value (1.2 for the case study)

Penalty 2: if load factor is less than minimum value (1 for the case study)

Penalty 3: if fleet size exceeds a minimum value (25 for the case study)

Penalty 4: if some demand remains unsatisfied

It is also observed in our typical traffic surveys that it takes about five minutes for commuters to reach at the bus stops located outside the station after arriving from DARTs. Thus transfer from a DART to a bus is feasible if the bus departs only after 5 minutes of scheduled arrival of the DART.

Step 6:

Find out percentage of demand satisfied by increasing / decreasing / changing the destinations as discussed in steps 4 and 5. Initially few nodes (destinations identified in traffic surveys) which are well scattered and away from the origin are selected, k – paths are developed for them and it is determined how much percentage of demand remains

unsatisfied after application of GAs. The additional destination is added and again it is determined if there is any improvement in satisfaction of percentage demand. The number of destinations for which maximum demand is satisfied is selected. Thus by gradually augmenting number of destination maximum possible demand satisfaction is achieved. The minimum number of destinations leading to maximum satisfaction of demand is selected as potential destinations. If entire demand is satisfied in a particular combination of potential destinations then corresponding feeder routes and frequencies (for determination of coordinated schedules) are optimum. If entire demand is not satisfied then go to step 7.

Step7:

Find out the nodes /nodes leading to unsatisfied demand and insert these nodes in the developed feeder routes by heuristic node selection and insertion process. The node selection and insertion process acts as repair heuristics and routes are modified. Due to limitation in the length of paper it is not possible to give details about this algorithm. In view of this readers are advised to refer Shrivastava and Dhingra (2001) for detailed discussion on node selection and insertion process / strategies. . In this repair heuristics following innovative ways are discussed for development of feeder routes:

- i. Determination of best path among others in which an identified node (destination) can be inserted. Path is selected based on saving in passenger walk time and increase in bus passenger time due to insertion of node.
- ii. After selecting best path the best way of insertion of node is identified. The best way is selected which gives least delay to destinations following inserted node.

Step 8:

Once all the nodes are inserted the developed routes are used for determination of frequencies using Genetic Algorithms leading to optimum coordinated schedules for the existing schedules of DARTs.

The objective function for this stage is simpler than the one which has been discussed in step 5. In the step 5 both routes and frequencies are determined using GA where as in this stage only frequencies are determined. Therefore the objective function involves only 1st term (transfer time between DARTs and buses) and 3rd term (Vehicle Operating Cost) along with all the constraints of step 5. In step 5 routes and frequencies were coded together where as in this step only frequencies are coded. Thus the analysis at this stage is simpler than what has been discussed in step 5. In view of this the details of application of Genetic Algorithm is not discussed here, moreover limitation with the length of paper does not permit detailed discussion. Thus it is advised that reader should refer Shrivastava and

Dhingra (2002) for detailed discussion on determination of coordinated schedules on fully developed feeder route network.

Use of Genetic Algorithms (GAs) for objective function and constraints

Genetic Algorithms (GAs) are based on exhaustive and random search techniques, found to be robust for optimizing non-linear and non-convex functions (Holland 1992). In this research Generational GAs with Reproduction, Crossover and Mutation operators is used (Goldberg 1989). The penalty method of constrained optimization is adopted (Deb 1995).

The proposed objective function is used with LibGA software of Genetic Algorithms in Linux environment to determine optimal frequencies on developed feeder route network (Lance Chambers 1995). Genetic Algorithms parameters are tuned for the objective function and thus type of process and best values of operators are decided. Roulette selection, simple random mutation and uniform crossover are adopted. Seed value as 1, pool size 30, crossover probability 0.85 and mutation probability 0.005 gave the lowest value of penalized objective function (objective function plus penalties). Thus these values are used for the analysis. A set of frequencies on various routes corresponding to the minimum value of the penalized objective function is used for determination of coordinated schedules on various routes.

The decision variables are routes and frequencies of buses during the application of Genetic Algorithm. The routes and frequencies are coded together in the same string. The most common coding method is to transform the variables to a binary string. GA performs the best when binary coding is adopted (Goldberg, 1989). The length of the string is determined as per the desired solution accuracy. In this study, routes and coordinating frequencies of each pair are coded into a single string. Figure 2 indicates typical binary digits coding for route no. 5 and route no.3 with frequencies 6 and 21 per hour. The first four bits show the route and last six bits show the corresponding frequency in a string.

The search space depends on the pool size and smaller pool sizes take less computational time. The case study discussed in the paper requires very less computational time as the size of matrix is very small. In case of big network and matrix pool size can be appropriately chosen based on convergence criterion. If smaller pool size is taken computational time will be lesser and values closer to optimal can be obtained, such values are practically acceptable for this type of problems. However such smaller pool sizes are to be tested with other operators and

parameters in the given problem. The heuristic part of algorithm does not take much computational time because few nodes are to be inserted on fully developed network.

RESULTS AND DISCUSSION

As discussed in the methodology well scattered minimum destinations satisfying maximum demand are selected as potential destinations. Maximum demand is satisfied when nodes 11, 12, 13, 15 and 16 are selected as potential destinations. Only 2.95% of demand remains unsatisfied for which heuristic node selection and insertion strategy is applied. Following routes are developed along with frequencies (for schedules) after application of Genetic Algorithms.

S. No.	Nodes in feeder routes	Length in 'km'
1	1 – 3 – 11	4.5
2	1 – 2 – 3 – 17 – 12	6.75
3	1 – 4 – 6 – 7 – 13	8.00
4	1 – 6 – 7 – 8 – 15	10.25
5	1 – 2 – 5 – 10 – 9 – 16	9.00

Since the developed feeder route network does not satisfy 100% demand, due to absence of destination node '14' in the above structure of feeder routes. Next stage of further modification of feeder routes using node selection and insertion strategies is adopted. Nodes are inserted / attached to above developed feeder routes. The frequencies associated to feeder routes in the earlier stage are discarded since fresh frequencies are required to be determined due to modification of routes. After applying heuristic node selection and insertion process the node 14 gets attached with third route and the length of third route increases from 8 km to 9.68 km. Figure 3 shows the finally developed five feeder route. Routes 3 and 4 partially overlap; also node '3' is common to routes 1 and 2. Thus the overlapping aspects of routes are also successfully attempted in this research. The connectivity between '13' and '14' could be established by repair heuristic. The node '14' was not included in the approach of Shrivastava O'Mahony (2006) as its demand was not satisfied by the approach adopted and was omitted.

In the development of routes the origin (DART station) remains same for all the destinations therefore all the feeder routes originate from DART station only. Thus it looks very similar to spanning tree rooted at DART station (figure 3). However the best alternative path out of selected k – paths for each set of origin and destination is

developed by combination of Genetic Algorithm and Heuristic approach. In some of the earlier approaches links on spanning tree are added / removed to get best network. Thus the approach adopted in this research is quite different.

Table 2 indicates coordinated schedules of feeder buses for the existing schedules of DART and the average load factors on each route. It can be seen in the table that load factor varies in the range of 0.33 to 0.83. These load factors will further improve due to local demands at en-route stops. The local demand is not considered because the routes are designed for feeder buses from DART station. Hence satisfaction of demands which generate from DART station is of prime concern. The overall load factor attains a value of 0.58 which is much improved value against the present scenario in which load factor remains in the range of 0.2 to 0.3 even during peak hours. Feeder routes and coordinated schedules for the same study area were developed by decomposing the problem in two stages: one for development of feeder routes using heuristic approach only and another for schedule coordination with Genetic Algorithms (Shrivastava and O'Mahony, Jan 2005). The load factors for different routes were in the range of 0.16 to 0.45 with overall load factor as 0.36. Thus the load factors and overall load factor by the proposed model have improved values. A comparison between existing scenario and improvement due to proposed model is given in table 3. If all the routes viewed together then 42 % of demand is satisfied with in 5 minutes of effective waiting and 29 % is satisfied between 6 to 10 minutes of waiting. Thus more than 70% of demand is satisfied with in 10 minutes of effective waiting. Entire demand is satisfied with in 20 minutes of effective waiting. In the present scenario majority of commuters have to wait 20 minutes or even more for buses and the load factor is also less than 0.3 during most of the time even during peak hours. Route wise details provides that on route number 2, 62 % of demand is satisfied with in 5 minutes and entire demand is satisfied with in 10 minutes of effective waiting. Route number 2 carries about 31 % of the total trips thus making this route as maximum trip carrier. In all the routes more than 50 % of demand is satisfied with in 10 minutes of effective waiting. In the developed feeder route structure lengths of routes vary between 4.5 km to 10.25 km and 100% demand is satisfied without any transfer. If similar exercise is carried out by identifying influence area of all stations shorter feeder routes will be developed which will be better in maintaining schedules (Shrivastava and Dhingra, 2001). This is due to the fact that one node may be connected to more than one DART station and its connectivity will certainly be better with shorter connecting length from one particular station only. It can be seen in figure 3 that destinations like Stillorgan (code-8), Mount Merrion (code-13) University College Dublin (code-14) and Dundrum (code-15) are closer to Blackrock

DART station as compared to Dun Laoghaire. Thus feeder routes for these destinations from Blackrock will be shorter.

The modelling exercise is carried out only for morning peak hour. The frequency of buses will change in the other hours of the day as per the demand. In fact traffic surveys should be conducted for whole day covering both peak and off peak hours and same methodology can be implemented to determine coordinated schedules of public buses during different periods of day. The whole day travel pattern will provide more realistic demand to different destinations for development of feeder routes, schedules and optimum fleet size for different periods of the day.

CONCLUSIONS

In the proposed model well scattered destinations away from the DART station satisfying maximum demand were selected as potential destinations. Feeder routes and frequencies leading to coordinated schedules were developed simultaneously from DART station to selected potential destinations using Genetic Algorithms. Preferably number of potential destination are selected as minimum as possible with maximum demand satisfaction. Selection of minimum destinations leads to less number of routes. If demands at some destinations remain unsatisfied then with the help of heuristic algorithm which works as repair algorithm such destinations are inserted/added to developed feeder route structure. After modification of route structure GAs are again applied to determine modified coordinated schedules. Following conclusions can be derived from the proposed modelling exercise.

1. In the proposed modelling exercise the optimised feeder routes and coordinated schedules are developed together in the 1st phase. Most of the routes are developed along with the coordinated schedules in this phase only. The coordinated schedules are further checked with second application of GAs. Thus in the proposed modelling approach most of the schedules and routes are complimentary to each other.
2. The model strikes a balance between users need and operators requirement. The objective function incorporates user costs in terms of time spent in buses and transfer time between DARTs and buses; the operators cost is vehicle operation cost which is directly proportional to distance travelled by buses. Similarly constraints also as per the requirements of users and operators. Load factor constraint is kept within minimum and maximum values so as to maintain better level of service for users and economic operation to satisfy operators. The fleet size constraint also a realistic constraint from operators' point of view. Constraint for unsatisfied demand

increases the probability of availability of seats to commuters though it is not very important when load factor remains less than a minimum value as has been experienced for the study area.

3. The selection of nodes as potential destinations plays a very important role for successful development of feeder routes for the typical locations of destinations in study area network under consideration. The network which is considered for analysis has nodes well scattered in the influence area and destinations having higher demands are closer to origin (DART station). Some of the destinations away from DART station have limited connectivity with other nodes. Selection of potential destinations away from the origin and well dispersed in the influence area develops feeder route structure which satisfy the maximum demand without any transfer.
4. The influence area of each station can be identified and the modelling exercise can be repeated with large scale data collection for whole day, thus a fully integrated system can be developed in which DARTs can work as a main line haul facility and buses can feed the local areas. The coordinated schedules of buses can be found for each period of the day and hence their requirement can be determined for peak and off peak periods. The proposed methodology is able to design feeder routes without any further transfers and the entire demand is satisfied directly from the DART station. The model takes into account the overlapping aspect of different routes successfully.
5. On average, the developed model is able to satisfy more than 50% of demand within ten minutes waiting time and the entire demand is satisfied within twenty minutes of waiting time with an overall load factor of more than 50%. On some routes, 80 to 90 percent of demand is satisfied within ten minutes of waiting and many routes have load factors even more than 0.7. In the present scenario (not optimised), the load factor hardly attains a value more than 0.3 and also the average waiting time is in the range of 20 minutes or more. Thus the proposed model judiciously balances waiting time and load factors for feeder buses.
6. The research problem which has been attempted is solely on development of feeder routes and not a usual network design problem. Genetic Algorithm has been successfully implemented for usual network design problems where transfer from one route to another is permitted i.e. passengers are assumed to take transfer from one bus to another. In the design of feeder routes it is not appropriate to incorporate additional transfers on routes because passengers are already subjected to a transfer from train to bus. Therefore additional transfers will lead to inferior design of feeder route network. Thus the application of 'Repair Heuristics' adds to development of feeder routes without additional transfers.

The proposed model can be implemented for development of feeder routes and coordinated schedules to any other study area if demands to various destinations and network connectivity details are known. Fully optimized feeder routes would be developed if higher demand nodes are well scattered and away from DART / railway station by Genetic Algorithm itself, otherwise repair heuristic will modify the feeder routes developed by GA. Moreover feeder routes without additional transfers are desired by planners. Other factors like transfer time, load factors in buses, fleet size, vehicle operating cost and availability of buses to all commuters are duly taken care both from users and operators point of view. Hence it can be concluded that the developed model can be of specific use to service planners working for coordinated operations of public transport modes.

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TABLE 1 Potential Demand to Various Destinations

Node No. (code)	Destinations	Potential demand to various destinations		
		7 – 8 a.m.	8 – 9 a.m.	7-9 a.m.
1	Dun Laoghaire DART Station	00	00	00
2	Dun Laoghaire College	39	202	241
3	Sallynoggin	17	103	120
4	Monks town	10	63	73
5	Deans Grange	16	93	109
6	Temple Hill	02	06	08
7	Black Rock	08	46	54
8	Stillorgan	13	77	90
9	Leopards town	02	08	10
10	Foxrock	02	08	10
11	Maple Manor / Cabinteely	02	04	06
12	Lough Linstown	13	78	91
13	Mount Merrion	02	15	17
14	University College of Dublin	04	23	27
15	Dundrum	06	31	37
16	Sandyford	03	15	18
17	Rouches Town Avenue	02	04	06

Table 3: Comparison between existing and proposed route network

Property for comparison	Existing Rout network in the study area	Proposed route network for the study area
Type of route network	Not a feeder route network	Feeder route network
Average load factor on routes	Less than 0.3	Over all load factor is 0.58 and is greater than 0.3 on all routes
Waiting time / percentage demand satisfaction	Average waiting time is more than 20 minutes	42% of demand is satisfied with in 5 minutes, 71 % with in 10 minutes and 100 % is satisfied with in 20 minutes of effective waiting.

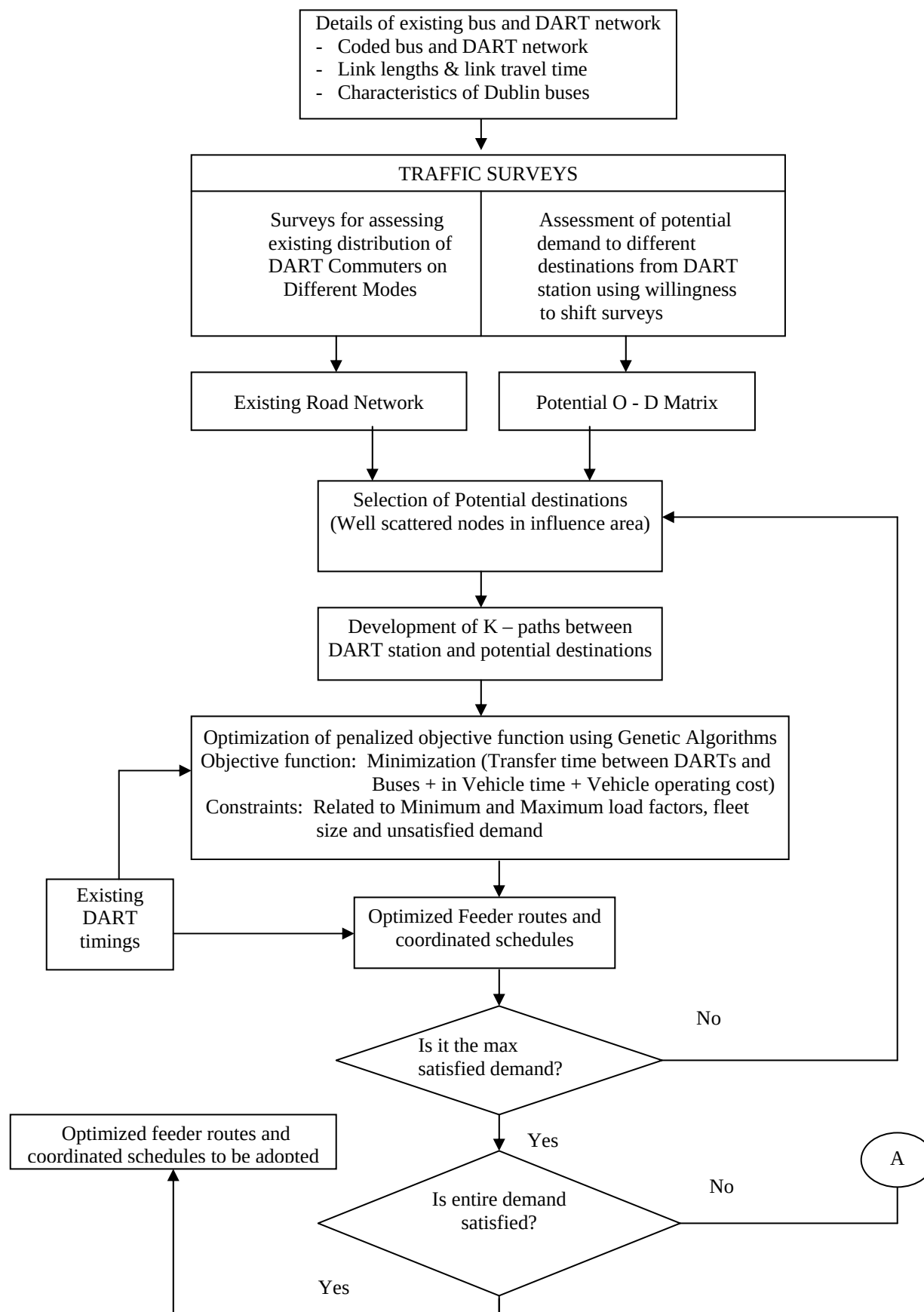


Figure 1 Methodology for development of feeder routes & coordinated schedules

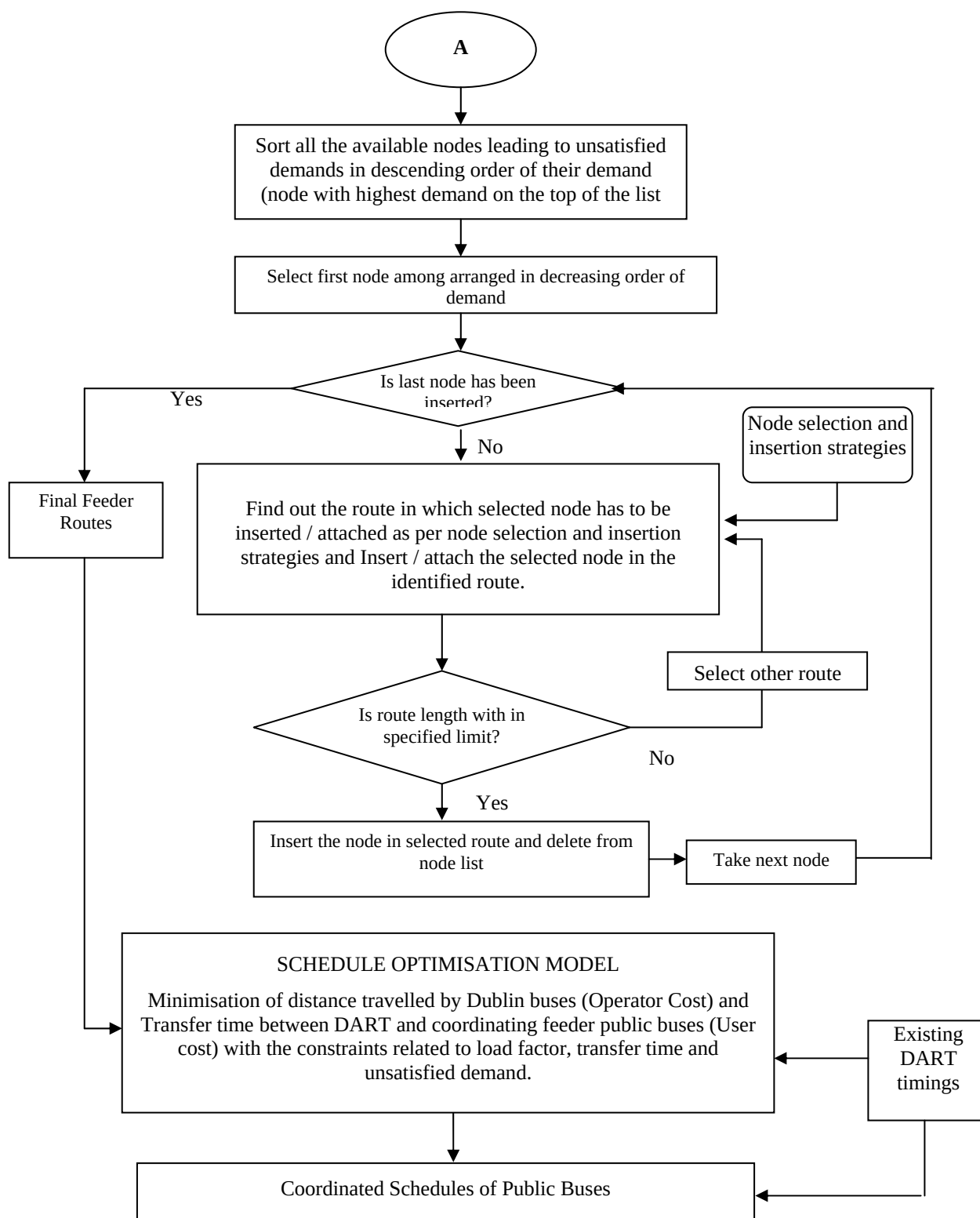


Figure 1 Methodology for development of feeder routes & coordinated schedules (Continued)

Pair no 1										Pair no 2									
Route				Frequency						Route				Frequency					
0	1	0	1	0	0	0	1	1	0	0	0	1	1	0	1	0	1		
Route no 5				Frequency 6						Route no 3				Frequency 21					

Figure 2: Binary digit coding

